A Study on the Operator's Erroneous Responses to the New Human Interface of a Digital Device to be Introduced to Nuclear Power Plants

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Abstract. It is extremely difficult to investigate completely the defects in digital devices, and to prevent human errors in their interface during the design aspect of nuclear power plants (NPPs). Human interface errors have been investigated through usability studies and reliability analysis (HRA). Several methods and various programs are available for prevention of human errors. However, it is very limited to explain the detail mechanism of human errors by quantitative usability approaches. Therefore, we define Error Segment (ES) and Interaction Segment (IS) to predict a specific human error potential (HEP) in a digital device and its human interface. In this study predicted HEP is to be verified by experiments including data analysis of EEG, ECG and behavioral observations. Thus the HEP in the human interface of a digital device can be more carefully considered for preventing human errors in NPPs.

Keywords: human error, EEG, ECG, nuclear power plant, human interface.

1 Introduction

Human error means the potential to reduce the system efficiency, safety and performance. Researchers have tried to predict and prevent all human errors. However, it has been complicated to understand human error in past control room design that had been established by high technology digital instruments. This is due to the existing quantitative methods that include HRA and usability studies being problematic when considering marginal human errors by using new digital devices. Thus, it is necessary to predict the error potential specific to the device prior to the design. A new method is proposed to find out human error potential to digital device human interface [1]. The objective of this study is to verify the predicted erroneous responses by measuring physiological signal (EEG and ECG) and observing the human behaviors. By determining ISs according to the unit's physical exterior and operational options of the digital devices, and tested them as ESs.

Initially *Error Segment (ES) and Interaction Segment (IS)* are established and investigated by selecting two smart-phones (named A and B) [1, 2]. They have been used restrictively in NPPs. Type A has fewer physical exterior units and fewer segments than Type B. Table 1 shows a few ISs. We found a case of HEP at 'V+' in ES and 'Horizontal mode' in IS. Operators interpret the Volume increase button (V+)

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differently according to a no option and a horizontal mode in IS. However they showed the same responses. When V+ is in the horizontal mode, it resulted in turning down the volume. It causes confusion to subjects by violating the interface design standard on space compatibility. If V+ of ES is in a horizontal mode, the volume decreases by stage or rapidly. Because V+ is on the left of the device in the horizontal mode, subjects are likely to push the left button for decreasing the volume [2].

Table 1. The example of HEP from IS and ES of A and B type smart phone

ES	IS					
Code.	Operation method	Operation situation				
		No option(Vertical)	Manner mode	Horizontal mode	Multi task	Lock
P	One Click	Screen on/off				
	Long Click	Pup-up window for option				
V +	One Click	Volume up by stages	Manner mode cancel and volume up by stages	Volume up by stages (space compatibility violation Operation intention: down	Volume up by stages	None
	Long Click	Volume up rapidly	Manner mode cancel and volume up rapidly		Volume up rapidly	None
V -	One Click	Volume down by stages → manner mode	Vibration	Volume down by stages (space compatibility violation) Operation intention: up	Volume down by stages → manner mode	None
	Long Click	Volume down rapidly → manner mode	Vibration		Volume down rapidly → manner mode	None
T	Rotation	Move	Move	Move	Move	None
	Click	Selection	Selection	Selection	Selection	None

2 Experiments

We conduct an experimental verification to confirm the predicted HEP at 1.1. Two kinds of smart phones currently used by NPPs with some functions (logging system) are named type A and B. The Type A smart phone has fewer physical exterior units and fewer segments than those of type B. Five graduate students who were not familiar with the device (smart phone) procedures participated for monetary compensation on a voluntary basis. It was assumed that subjects were all on the same level of task procedure knowledge. The five subjects can be regarded as representative participants. Subjects were informed of the experiment method, and randomly complete each trial. After each trial was completed, ten minutes of rest was provided to the subjects. The task for this experiment is shown in (table 2). Task 2 was considered with the HEP.

The experiment includes three steps. The first one is a video recording and observation to determine the error rate and task performance during tasks. The second one is analyzing EEG/ECG by their frequency trends and patterns. These approaches are to find out the error potential and non-error section. There are several analysis methods to understand including law data graph trend, specific frequency pattern, brain activity, and statistical approach. After the experiments, all subjects evaluated their subjective workload by NASA-TLX. Figure 1 shows the experiment process.

EEGs and ECG were recorded in 8 channels by *POLYG-I of Laxtha*. It was measured by international 10-20 lead standard. Fp1, Fp2, F3, F4, P3, P4, O1, O2 leads were used with Ag/AgCl electrodes. The impedance was below 10□ on all electrodes. Physiological signals were filtered by band pass filter, and sampled by 512Hz. The EEG components of the following four frequency bands are obtained delta (0.5~3.5Hz), theta (4~7Hz), alpha (8~12Hz), and beta (13~30Hz). We analyzed $\beta/(\alpha+\beta+\theta+\delta)$ by frequency band and also confirmed brain activity by mapping during performing tasks.

Table 2. Tasks designed for experiment

Step	ES	IS Task 1	IS Task 2	Performance Item
1	P			Power and screen on
2	M, I, T	One click **No option**	One click **Horizontal Mode**	Take a picture in the field
3	I, B			Send the message to MCR with short message
4	V			Turn down the volume during step 3

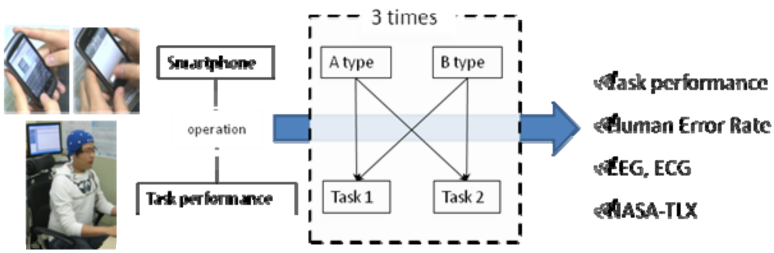

Fig. 1. The experiment procedure

3 Experimental Results

We tested the error rate, task performance (reaction time), EEG, ECG, NASA-TLX. Subjects were required to completely perform all preset task steps in the each task. The number of steps to complete the task was fixed. The total steps executed by a participant minus the steps preset would be the number of human errors. The number of error times was significantly more in task 2 than task 1 and significantly less in type A than type B. The average error rate is presented in table 3. Based on the results, there were significant differences between task 1 and 2 except the third repetition (*: $p\text{-}value<0.05$, **: $p\text{-}value<0.1$). The highest error rate was appeared in step 4. It was getting decreased after practicing about three times. The task performance of participants on different task types was analyzed as the reaction time. The reaction time between A and B type smart phone was significant ($p\text{-}value<0.05$). Also, the results showed that the average task performance (reaction) time was significantly different between task 1 and 2 (table 3). In the third repetition, there was no significant difference between tasks but the reaction time was the shortest. When a subject had an error in a specific part, the reaction time had sharply increased. One subject was confused and repeated the same procedure several times even though he was right because he didn't know whether it's right or not. One other subject performed the same task very quickly although he made errors. Thus, there was no correlation between reaction time and error.

Table 3. The results table for error rate and reaction times

Repeat		Error Rate(%)				Reaction Time(s)			
		A type		B type		A type		B type	
	Analysis Items	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2
1	average	42	52	60	66	358.7	374.74	433.4	448.78
	S.D	10.95	4.47	7.07	8.94	41.45	54.13	50.11	52.34
	P-value	0.034*		0.007*		0.054*		0.077*	
2	average	22	30	36	42	279.98	311.76	359.8	374.32
	S.D	4.47	7.07	5.48	8.37	27.25	24.70	30.20	23.69
	P-value	0.099**		0.208		0.003*		0.01*	
3	average	10	14	22	24	147.82	230.26	252.6	273.18
	S.D	0	5.48	4.47	5.48	28.54	63.35	98.64	91.53
	P-value	0.374		0.178		0.696		0.225	

NASA-TLX results show that subjective workload of participants between task 1 and 2 were significantly different (*t=-2.807, p-value=0.038*). In task 2, all items had higher value than task 1. However, there was no significance difference between smart phone types. It shows that most participants had higher mental focus and concentrated efforts in performances than physical, temporal demand and frustration levels. (table 4).

Table 4. NASA-TLX

NASA-TLX		Mental	Physical	Temporal	Effort	Performance	Frustration
A type	Task 1	52.6	20.4	35	60	64	36
	Task 2	54	24	40	74	78	38
B type	Task 1	47.2	21	33	68.8	70	35.6
	Task 2	68	30	52	70	80	74

The heart rate in rest phase was continually recorded by ECG during and before the experiment. The heart rate difference was calculated in the rest status subtracted from average heart rate. The result shows that there was no significant difference between task1 and 2, and error and non-error section. Thus, heart rates by task types and error potential did not show any differences even though subjects felt some load subjectively.

Average beta activity of EEG data was showed as $\beta/(\alpha+\beta+\theta+\delta)$. The trends between task 1 and 2 look similar. The average beta band activity was increased from the front to the back of the brain. It was shown same results in type A and B, and there was significant difference between tasks (*p-value<0.05*). Figure 2 shows a comparison between error section and non-error section. Several statistical analyses were applied to the pattern of EEG graph, specific frequency band activity, and brain mapping. The error and non-error section could be separated by frequency band shown in figure 2. The error section has more frequency band than non-error one (*p-value<0.05*). However, the frequency data were mixed by noise; it is not easy to separate precisely.

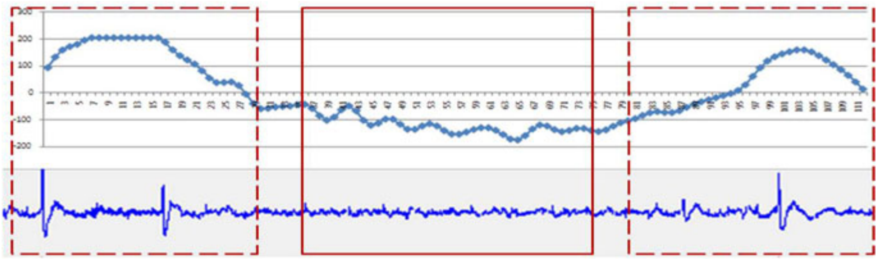

Fig. 2. The error and non-error section of a channel of EEG, the top graph is raw data from EEG according to recording time and the down graph shows two error section

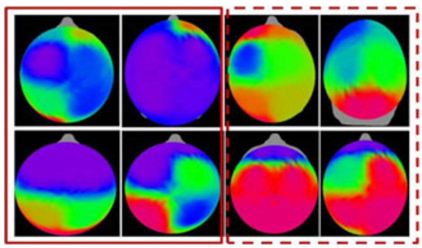

Fig. 3. The brain mapping between non-error and error section

Second, the section could be confirmed by brain mapping. The red area showed the brain activity was high. The high brain activity appeared when subjects concentrated on the task and became nervous because they had made an error.

4 Conclusions

Many alarms and user-friendly display features in digital devices were not enough to prevent human error in NPPs. The most urgent demand is to find out the detail mechanisms of human errors of digital device, and then consider them during the digital device interface design in NPPs. This study experimentally tried to verify the HEP predicted by ES and IS of a digital device by observation and measurement of EEG, ECG. We could discriminate the difference between error and non-error section, but it was not sensitive enough. A more detailed analysis technique is necessary to compare between the error section and non-error section. Since we are in a primary stage to find out the human error potential by experiments, further study is demanded to introduce the digital device without any human error in NPPs.

References

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